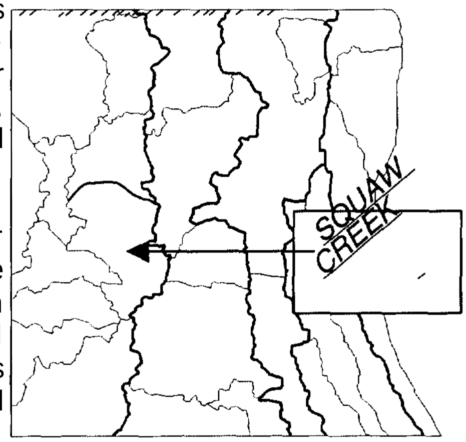
Use of Automated Technologies in Watershed Management Planning

Lake County Stormwater Management Commission (SMC)
Libertyville, IL

Introduction

The Lake County Stormwater Management Commission's (SMC) is working with many agencies to develop comprehensive watershed plans. These watershed plans involve data collection and collation, problem analysis, alternative solutions identification and action plan development. The watershed assessment includes hydrologic and hydraulic modeling; floodplain and floodway mapping; and water resource assessment. As part of a watershed management plan, one of the end results is to update floodplain maps and to map depressional storage areas. Other end products of this effort include location maps of water resources, including wetlands and regional detention sites, with identification of those needing preservation, enhancement or restoration. With this information, projects can be prioritized and cost estimates determined in order to assist local governments in implementing the action plans.

Lake County, Illinois is located in the northeastern corner of Illinois and is one of the fastest growing counties in the country. The county has 61,000 acres of wetlands (12) and 400 miles of streams and rivers throughout its 480 square miles. The combination of growth and the need to protect natural resources is driving the Lake County Stormwater Management Commission's (SMC) comprehensive watershed planning efforts. Plans are currently being developed for urbanizing watersheds between 2 and 50 square miles in area.



Map 1: Lake County, Illinois, Sub-Watershed

With limited personnel and funding, SMC is utilizing in-house computer capabilities and staff technical expertise to save time and money as we increase our ability to model and display watersheds. The Squaw Creek Plan is an example of how SMC is currently utilizing automated technology for watershed planning purposes. The Squaw Creek watershed is 25.5 square miles and is 75% undeveloped (includesagriculture, vacant and open space). The watershed is 17.3 percent wetlands. TheNorthern Illinois Planning Commission forecasts a 155% population change between 1990 and 2020. The Squaw Creek Watershed is located in the western portion of the county and drains into Fox Lake, on the Fox River.

SMC is integrating Geographic Information System (GIS) (2) technology with Computer Aided Design (CAD) and the Army Corps of Engineer's HEC-1 (10) and HEC-RAS (11) models to create an "automated" watershed closely resembling the existing Squaw Creek watershed characteristics. SMC used a variety of vendor software packages that include Environmental Systems Research Institute, Inc.'s (ESRI) ArcView (1) and its Spatial Analyst and Hydrologic Extensions, and Bentley's MicroStation.

Data Collection

It is very important to determine the methodologies for collecting, calculating, and analyzing data early in the automation process. Methodologies were determined for mapping floodplains, inventorying and analyzing water resources (8), and estimating runoff water quality. The floodplain mapping variables included time of concentration, precipitation runoff, stream storage, stream routing, sub-basin boundaries, and water surface elevations. Thesevariables had to be determined before final data could be formatted and collated. We also had to determine how data could be documented in the report early in the study process,

Since considerable map data was available digitally, it was economical to perform many tasks on the computer rather than on hard copy. The Northern Illinois Planning Commission (NIPC) provided the digital land use map. Lake County Map Services provided digital copies of the Soil Conservation Service (SCS) hydrologic soil groups (HSGs) map, hydric soil map, United States Geological Society (USGS) orthophotos, Lake County Wetland Inventory boundary map, and Lake County parcel boundaries. In addition to this digital data, SMC contracted to obtain 2-foot topographic contours, detailed orthophotos, stream cross-sections, and field-surveyed hydraulically significant structures. Bridge and culvert information and stream cross-sections were also delivered digitally from Illinois Department of Natural Resource's (IDNR) land survey crew using Global Positioning System (GPS) and conventional surveying. Photogrammetry and cross-section control points were collected in the field utilizing a GPS with accuracy of 1:50,000 horizontal and +/- 0.03 feet vertical (5). Each USGS digital orthophoto map covers one quarter of a quadrangle and used 45 MB of computer storage. The topographic maps weredelivered in GIS and CAD formats. Contracted data were delivered by square mile. This created a reasonable size data file, including:

Two foot topographic contours and breaklines	1.2 to 3 MB per square mile.
Orthophotos	35 MB per square mile
Digital Elevation Model	1 MB per square mile

The cost for the two foot contours overlaid on an orthophoto varied between $2200 and $3300 per square mile. Additional record drawings of hydraulically significant structures, such as road crossings and detention basin outlets, were collected from county and state highway departments and local communities. The townships and communities seldom had detailed information, so field investigations were undertaken, where necessary, using topographic mapping to establish a reference elevation.

The water resources inventory included a stream assessment, wetland inventory, and a wetland restoration assessment. The stream assessment data were collected in the field along with short community interviews. The stream inventory used an existing methodology created by NIPC (8). SMC created a methodology to identify potential wetland restoration locations.

Surface runoff water quality was estimated using typical measured pollutant loading data for several general land uses. NIPC had an existing procedure that assigned non-point runoff pollutant loads to general NIPC land uses. The typical pollutant loadings were entered into a worksheet so this procedure could be automated.

Creating Hydrologic and Hydraulic Data

Several hydrologic and hydraulic parameters and other data were used to analyze the surface water runoff and generate floodplain boundaries. These included delineating sub-basin boundaries; determining a runoff curve number, time of concentration and Clark's coefficient of runoff for each sub-basin; calculating reservoir data; formatting HEC-1 model; and creating HEC-RAS model geometry.

Sub-basin Delineations

The sub-basin boundaries were produced automatically using the following steps. First, a Digital Elevation Model (DEM) was produced from photogrammetry by a consultant. A DEM is a list of equally spaced data points with a defined easting, northing, and elevation. A spacing of the DEM points of 10 and 30 feet was evaluated. The lo-foot spacing would slightly increase the accuracy of the automated sub-basin boundary's but it used ten times the disk storage as the 30-foot spacing. Therefore, a 30-foot grid DEM was used to determine the sub-basin boundaries due to storage space limitations. Second, the DEM was loaded into ArcView and converted to a DEM grid using ArcView's Spatial Analyst. Third, the flow paths and the preliminary sub-basin boundaries were created using ArcView's Spatial Analyst and Hydrologic Extension along with the DEM grid, which delineated 180 preliminary sub-basin boundaries in 2.5 hours.

Fourth, these preliminary boundaries were edited with the digital contour map in the background to better model storage areas and road crossings. This editing entailed splitting basin boundaries and joining basins together to produce more accurate boundary lines. Editing was performed on portions of approximately 50% of the preliminary sub-basins that were automatically created and ultimately reduced the number of sub-basins. Edited boundaries were checked against hard copy maps and a field investigation of storm sewers and field tiles. A check of maps and field investigation identified three boundaries that needed additional modifications including the addition of one sub-basin. Finally, ArcView was used to automatically calculate each sub-basin's area and a sub-basin identification was assigned to each of the 140 sub-basin areas.

Runoff Curve Number

SMC created a methodology to estimate precipitation runoff. This required converting SMC defined land use categories to Soil Conservation Service (SCS) runoff curve numbers (RCNs) (9) using ArcView and Excel (6). RCNs were calculated using the following sequence. First, the 1990 NIPC land use polygons were converted to SMC land use categories based on land cover using 1996 orthophotos as a backdrop. Land cover was divided into six categories: 1) impervious, 2) graded grass, 3) natural grass, 4) graded forest, 5) natural forest, and 6) agriculture. Typically graded grass and graded forest land cover categories have increased runoff compared with their natural conditions as soils are compacted and depressions are removed during grading. A SMC land use was created for the calibration year of 1996 and for the model year of 2000. Second, concurrently with the land use conversion, the digitally mapped soil numbers were converted to HSGs using GIS queries. Third, the HSG map was intersected with the SMC land use categories to automatically create a land cover map. Fourth, the land use categories table and a land cover conversion table were joined so there was one RCN for each of the four HSGs.

Runoff Data

HEC-1 requires specific input data to generate runoff volumes for each sub-basin. The minimum input parameters for each sub-basin were identification, area, the time of concentration (Tc), Clarks Coefficient of Runoff(R), and weighted RCN. Sub-basin area was delineated as previously described.

The weighted RCN was determined in two steps. First, intersecting the finalized sub-basin boundaries with the RCNs boundaries using ArcView. This splits the RCN polygons with the sub-basin boundaries. This calculation took just twenty minutes. Then this table of RCN attributes for each sub-basin was exported from ArcView into Excel where the weighted curve number for each sub-basin was calculated in one day.

In addition, each sub-basin requires a length and slope of travel to generate the Tc and R. To determine the length and slope, a line with two points were needed, one upstream and one downstream. The line represented the direction of runoff from the farthest ridge to the outlet of the sub-basin. GeoAnalytics, Inc., a consultant, created a program to automatically generate a distance point 10% and 85% from the sub-basin outlet along this digitized line in 30 seconds. The point locations along the line were determined by the methodology used to estimate Tc and R. These points were queried individually with the DEM grid and checked against the topographic map to determine their elevation, which was entered into a table, ArcView calculated all sub-basin line lengths in less than a minute. The stream line and its two elevation points were associated with the sub-basin identification throughout this process. Next, the sub-basin boundaries, the associated line, and two points were joined into one table and exported as a database file. This database file was imported to an Excel worksheet where the slope, Tc, and R were calculated for each sub-basin.

Reservoirs

To model reservoir routing, the reservoir volumes were determined using ArcView and the 2-foot digital contours. The reservoirs consisted of a series of polylines in ArcView after conversion of the CAD contour map. The polylines were modified so they were completely connected and then converted to a polygon in ArcView. This documented the location of every reservoir that was modeled explicitly, as not all reservoirs could be modeled within the scope of our project. Second, the elevation for each contour was entered into a table. The topographic contractor now performs steps one and two. After all the elevation polygons were created, ArcView calculated the area of the polygons with one command.

Finally, the elevation and area tables were opened in an Excel worksheet to calculate the elevation versus storage relationship. This worksheet was referenced by the HEC-1 formatted worksheet described in the next section. Stage versus discharge relationship was determined for each reservoir when data was available using HEC-RAS or HY-8.

Hydrology Model Development

All of this data was combined into one Excel workbook to generate the input needed for HEC-1. The sub-basin data entry included: identification, area, weighted RCN, Tc, and R. Most sub-basins also needed reservoir or stream routing data. An Excel worksheet was edited with HEC-1 formatted column widths so the data could be saved into a file that the HEC-1 FORTRAN program can accept. Sub-basin data were entered automatically by referencing other worksheets in the same workbook. Once the first sub-basin referenced the other worksheets properly, the first formatted sub-basin data were copied to create another set of HEC-1 data for the next sub-basin. After the sub-basin identification was entered for this new HEC-1 input data set, the remaining data were automatically retrieved in the worksheet and correctly formatted, to avoid data translation errors.

Hydraulic Data

The stream cross-section data were initially generated in MicroStation. Each section was digitized as a series of connected line segments that were exported to a comma-delimited file of easting, northing, and elevation which was then imported into HEC-RAS's "Import/Export Files for Geospatial Data." The culvert and bridge data had to be coded in separately. The channel stationing was determined automatically using Intergraph In-Roads. This procedure not only provided data formatted to be exported directly in HEC-RAS, but also created a 3D map of the channel cross-sections and stream centerline to document the model spatially using MicroStation and ArcView. The cross-section segments had to be manually identified for use in the automated floodplain mapping.

Floodplain Development

Stream cross-sections and hydraulic structures were modeled using HEC-RAS to determine the water surface elevation along the stream. ArcView's Spatial Analyst Extension or ArcInfo could be used to delineate the floodplain from the HEC-RAS output. Final maps were generated in ArcView.

The HEC-RAS generated water surface profiles were exported by HEC-RAS's "Import/Export Files for Geospatial Data." GeoAnalytics Incorporated, Madison, Wisconsin, imported this data into an ArcInfo project that uses a 1 O-foot DEM grid. ArcInfo needs a line and an elevation for each cross-section to map the floodplain. The cross-section line and its identification were created in MicroStation, exported as comma delimited points, and then referenced into ArcView to create the cross-section line. The line with its cross-section identification was associated with the water surface elevation. The grid was then "flooded" between the two cross-sections with a linear slope between the appropriate water surface elevations. This creates a grid of the flooded area. For each flood profile that was to be mapped, a separate grid of the flooded area must be completed.

Reservoirs, such as lakes, ponds, and depressions, that have their Base Flood Elevations determined using HEC-1, were mapped automatically. The storage areas had the water surface elevation defined using HEC-1 then the grid was "flooded" for all points at or below that elevation.

The flooded grids were then converted to polygons and "smoothed" in ArcInfo for use in ArcView. Last the polygons were reviewed against the digital two-foot contours and adjusted as needed before final map production. Every reservoir outlet had to be manually mapped between its outlet and the downstream reservoir or stream floodplain.

Water Resource Assessments

A water resources inventory was completed that included a stream assessment, a wetland inventory, and potential wetland restoration site identification. All of the stream assessment data were collected in the field along with short community interviews and entered into a database. Several key stream characteristics were mapped using GIS. The stream inventory data were queried for specific stream conditions and key characteristics were mapped such as degree of bank erosion or sediment accumulation.

A county wetland Advanced Identification (ADID) study was completed in 1992 prior to the assessment. One of the criteria reviewed for each wetland was its storage potential, which was related to the area of the wetland. Querying the spatial data for specified wetland areas and creating a new set of data easily identified these wetlands. The wetland restoration and mitigation bank site identification methodology was developed by SMC in 1999. Several data sets were queried to identify the former wetland sites that have the greatest number of characteristics necessary to make them restorable and usable as a wetland bank. A less stringent set of criteria was used to define all former wetland sites with restoration potential. The potential wetland restoration sites included all Advanced Identified (ADID) wetlands. Potential wetland banking sites excluded ADID wetlands and restorable sites less than 20 acres.

Surface water quality 'hot spots" were estimated using non-point pollutant loading rates for several general land uses via NIPC methodology. Twelve pollutants were evaluated. The pollutant "hotspots" analysis employed land use, impervious surface area, annual runoff coefficients, and storm sewer conditions as surrogates to determine the annual pollutant loading by sub-watershed. The pollutant loading database was attached to the land use map database. It was then mapped in ArcView resulting in 12 maps, one for each pollutant.

The watershed advisory committee and NIPC identified which level of pollutant loadings should be labeled as detrimental. The pollutant load data were then grouped, using natural breaks in the data set, as low, medium or high. These were mapped and queried to determine where water quality enhancement projects would be most beneficial and highest priority.

Summary

The Lake County Stormwater Management Commission has invested a significant amount of time and funding in developing the hardware, software, and database necessary to perform floodplain analysis. By making this commitment and establishing the methodologies for manipulating data and analyzing watershed parameters, we have created a powerful analysis tool. Mapping accuracy, display flexibility and a wide range of GIS analysis ability has been created through this process. This technology coupled with other resource assessment efforts has created a strong foundation for future watershed planning in this watershed. The technology is transferable and will be used throughout Lake County as our agency resources allows.

References

Environmental Systems Research Institute, Incorporated (ESRI) ArcView, 1995, "Using ArcView GIS 3.0a" and "Spatial Analyst"

Environmental Systems Research Institute, Incorporated (ESRI) ArcView, 1996, "Using the ArcView GIS Spatial Analyst"

Lake County Stormwater Management Commission, 1994, Watershed Development Ordinance

Lake County Stormwater Management Commission, 1998, General Conditions of Topographic Mapping

Lake County Stormwater Management Commission, 1997, Attachment A, Field Survey and Data Collection

Lake County Stormwater Management Commission and GeoAnalytics, Inc., Madison, WI 53704, 1998, Lake County, Illinois Stormwater Management Commission, GIS Data Handling Procedures for Input into HEC-1

Lake County Stormwater Management Commission, Land Use to Land Cover Conversion Methodology

Northern Illinois Planning Commission, 1994, "Methods and Procedures for the Stream Condition Form," from Appendix A of Sequoit Creek Watershed Management Project.

Soil Conservation Service, Washington, DC, 1985, National Engineering Handbook Section 4 - Hydrology, PB86780494

U. S. Army Corps of Engineers, 1990 “HEC-1 Flood Hydrograph Package User’s Manual Version: 4.0”

U. S. Corps of Engineers, 1997 “HEC-RAS 2.0 River Analysis System”

U. S. Environmental Protection Agency, Region 5, Lake County Stormwater Management Commission, and Northeastern Illinois Planning Commission, November, 1992, “Wetland Advanced Identification (ADID) Study, Lake County, Illinois”